Fundamental parameters of Cepheids. V. Additional photometry and radial velocity data for southern Cepheids[1]

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ABSTRACT

I present photometric and radial velocity data for Galactic Cepheids, most of them being in the southern hemisphere. There are 1250 Geneva 7-color photometric measurements for 62 Cepheids, the average uncertainty per measurement is better than 0.01^m. A total of 832 velocity measurements have been obtained with the CORAVEL radial velocity spectrograph for 46 Cepheids. The average accuracy of the radial velocity data is 0.38 $\mathrm{km\,s^{-1}}$. There are 33 stars with both photometry and radial velocity data. I discuss the possible binarity or period change that these new data reveal. I also present reddenings for all Cepheids with photometry. The data are available electronically.

Subject headings: Cepheids — techniques: radial velocities — techniques: photometric — (ISM:) dust, extinction

1. Introduction

A significant amount of photometry and radial velocity data for Cepheids had been published by Bersier, Burki, & Burnet (1994) and Bersier et al. (1994). These have been used to devise a new version of the Baade-Wesselink method (Bersier, Burki, & Kurucz 1997). However most Cepheids in Bersier, Burki & Kurucz's sample are in the northern hemisphere. New observations have been obtained for (mostly) long-period Cepheids visible from the southern hemisphere. I present here these new observations, along with older unpublished data. The photometry is in the Geneva 7-color system and the radial velocity data have been obtained with the CORAVEL radial velocity scanner (Baranne, Mayor & Poncet 1979).

[1]Based on observations obtained at the European Southern Observatory, La Silla

2. Observations

2.1. Photometry

A search in the Geneva photometry database revealed that several Cepheids already had a substantial number of measurements. These data could constitute a basis for expanding Bersier et al.'s (1997) efforts to determine Period-Radius and Period-Luminosity relations via the Baade-Wesselink method. I present these old unpublished data[2] together with new data obtained in several runs during 1996 and 1997. Like the data given in Bersier, Burki, & Burnet (1994), the measurements are in the Geneva 7-color system (Golay 1980, Rufener 1988) and most have been obtained with the 70-cm Swiss telescope at La Silla Observatory. The instrument used is a photometer (Burnet 1976) that measures each filter several times per second; the exposure is stopped after a minimum signal-to noise ratio has been reached in each filter; the integration time was at least three minutes. Given that most of our stars are brighter than $m_V = 10$ the uncertainty is better than 0.01^m for virtually all measurements. Furthermore all measurements have been obtained in photometric conditions. Table 1 lists all 62 Cepheids that have data. The 1250 individual measurements in seven colors are given in Table 2[3]. Forty-three stars have more than 20 measurements. Figure 1 presents examples of light and color curves for well-observed Cepheids.

2.2. Radial velocity

Most observations were obtained in several runs on the 1.5 meter Danish telescope at ESO La Silla in 1996 and 1997, hence these data are contemporaneous with most of the photometry presented above. I used the CORAVEL spectrograph, described in detail in Baranne, Mayor & Poncet (1979). The instrument was optimized to yield accurate radial velocities through a cross-correlation method. The light is dispersed and then goes through a mask (based on the spectrum of Arcturus) before being detected by a photomultiplier. An arc spectrum is obtained just before and just after each star exposure, to provide a good wavelength solution. The observing setup is such that the cross-correlation function (CCF) is viewed in real-time. This allows to stop the exposure when the CCF has a sufficient signal-to-noise. A Gaussian is fitted to the observed cross-correlation function to yield the

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[2]the present paper contains only unpublished data. Other Cepheid data can be found in Bersier, Burki, & Burnet (1994) and references therein.

[3]All the data presented in this paper are available electronically at ftp://cfa-ftp.harvard.edu/pub/dbersier/

velocity.

A total of 46 Cepheids have been observed, representing 832 measurements. Twenty-four stars have 15 data points or more. Some stars have very few measurements though. They have been left out of the target list early in the program, when it has been realized that it would not be possible to obtain extensive phase coverage for all Cepheids before the instrument decommissioning. Table 3 gives the name of each program Cepheid and the respective number of measurements. Individual measurements and their associated uncertainties are given in Table 4. Given that most of the program stars are fairly bright, the average error per measurement is 0.38 $\mathrm{km\,s^{-1}}$. Examples of well-covered velocity curves are given in Fig. 1.

Results and discussion

2.3. Reddening

Following the method of Bersier (1996) it is possible to determine the color excess for Cepheids. This is based on the method of Fernie (1990), using two colors that are linearly related to each other. In Bersier (1996) there was a hint of a possible systematic difference with Fernie's scale. This became clearly apparent with the large number of stars available here when comparing both sources of color excesses (see Fig. 2), there is a problem for stars with $E(B-V) > 0.5$. The same problem was apparent when comparing my color excesses with those for Cepheids in open clusters (Feast & Walker 1987), which is not surprising given that Fernie's scale is ultimately tied to the reddening given by Feast & Walker (1987). The source of this problem might be in the small number of calibration stars with large $E(B-V)$ used in Bersier (1996). In order to remedy this situation, I determined a new calibration of the color excess, using more stars with $E(B-V) > 0.5$. As in Bersier (1996) I used F- and G-type supergiants in clusters and OB associations from the list of Arellano-Ferro & Parrao (1990) and supergiants with low reddening from Gray (1991). I also tried to use different combinations of colors. The best results have been obtained with

$$E(B-V) = 0.887 * (B_2 - V_1) - 1.623 * m_2 - 0.913 \tag{1}$$

where $m_2 = (B_1 - B_2) - 0.457(B_2 - V_1)$. The average error on the reddening so determined is 0.03^m. Figure 2 presents a comparison of the new reddenings with those of Fernie (1990), the agreement is now much better; a fit gives $E(B-V)_{F90} = 0.98E(B-V)_{here} + 0.02$. These new color excesses for 85 stars are given in Table 1.

2.4. Comments on individual stars

In most cases, I compared the CORAVEL data with already published radial velocity data, usually using the periods given in Szabados (1989). This is because a number of Cepheids have been suspected to be binary or to have a changing period.

U Car It is clearly a binary. My data are offset from Coulson & Caldwell's (1985, hereafter CC) velocities by more than 10 $\mathrm{km\,s^{-1}}$.

VY Car The large phase offset between the CORAVEL+CC data and Stibbs (1955) data suggests a period change.

XX Car Even though there a few new data points, it is enough to show that this star is a binary. The CORAVEL data are offset by about 30 $\mathrm{km\,s^{-1}}$. with respect to CC's data.

V Cen Szabados (1989) suggested that this could be a binary. Adding data from Stibbs (1955), Lloyd Evans (1980) and Gieren (1981), the evidence for binarity is marginal. Lloyd Evans velocities are shifted by only ~ 2 $\mathrm{km\,s^{-1}}$ with respect to CORAVEL+Gieren. Stibbs' data only add scatter.

V659 Cen Photometric measurements made around $HJD = 44600$ are shifted in phase with respect to measurements obtained around $HJD = 50100$.

S Cru The CORAVEL data are shifted by 2.7 $\mathrm{km\,s^{-1}}$ with respect to Gieren's (1981) data. The period giving the best Fourier fit ($P = 4.689838^d$) is longer than what is predicted by Szabados (1989) ephemeris ($P = 4.689392^d$).

T Cru The binarity suspected by Szabados (1989) is confirmed. The data from Lloyd Evans (1980) are shifted by about 4 $\mathrm{km\,s^{-1}}$ with respect to mine. Stibbs (1955) data are also significantly shifted, giving a lower limit on the amplitude of $\sim 8\,\mathrm{km\,s^{-1}}$.

SY Nor Binarity was suspected by Madore (1977). Bersier et al. (1994) confirmed the binary nature on the basis of radial velocity measurement. With the data published here, and adding the data of Metzger et al. (1992) it is possible to constrain the orbital period

at $P_{orb} = 551.7^d$. When folded with that period, the orbital amplitude is approximately 30 $\mathrm{km\,s^{-1}}$.

AQ Pup Even though I have only two measurements, adding the data from Stibbs (1955), Coulson & Caldwell (1985) and Barnes, Moffett, & Slovak (1988) clearly shows that the period is changing.

Y Sgr Szabados (1989) gives evidence that this is a binary. The present data seem to support an orbital period around 10000 days.

WZ Sgr The data from Coulson & Caldwell (1985) are clearly shifted with respect to the CORAVEL data. This confirms the binary nature of this Cepheid (Szabados 1989). The measurements from Gorynya et al. (1996) do not show any shift in γ-velocity with respect to mine.

RZ Vel Using data from Stibbs (1955), Lloyd Evans (1980) and Coulson & Caldwell (1985), this star seems to show evidence for binarity and for a changing period.

AH Vel This star is a known binary, although the orbital period is not known yet (Szabados 1989, and references therein). The γ-velocity determined from CORAVEL data is almost identical to that given by Stibbs (1955). Unfortunately the present data do not put much constraint on the orbital period.

Several Cepheids in this sample are known binaries. The list of known binaries for which I present data include U Aql, η Aql, YZ Car, XX Cen, DX Gem, S Mus, U Sgr, X Sgr and Y Sgr. Apart from those that have a published orbit, evidence for binarity include the presence of a UV-bright companion, long-term shift in the γ-velocity or evidence from the photometry. One of the primary motivations for publishing the present data set is that it will provide additional radial velocities allowing to obtain orbits for several binary Cepheids. Also, some light and velocity curves are good enough to be used for a Baade-Wesselink analysis.

It is a pleasure to thank J.-C. Mermilliod, F. Kienzle and F. Pont for their help with the observations, and S. Udry for extracting the velocity data. I thank the referee for comments that improved the presentation of this paper. This work has been supported by NSF grant AST-9979812. I also acknowledge partial support from the Swiss NSF through grant 8220-050332.

REFERENCES

Arellano-Ferro, A, Parrao, L. 1990, A&A, 239, 205

Baranne, A., Mayor, M., Poncet, J. L. 1979, Vistas in Astronomy, 23, 279

Barnes, T. G., Moffett, T. J., & Slovak, M. H. 1988, ApJS, 66, 43

Bersier, D. 1996, A&A, 308, 514

Bersier, D., Burki, G., & Kurucz, R. L. 1997, A&A, 320, 228

Bersier, D., Burki, G., & Burnet, M. 1994, A&AS, 108, 9

Bersier, D., Burki, G., Mayor, M., & Duquennoy, A. 1994, A&AS, 108, 25

Burnet, M. 1976, PhD thesis No 232, Ecole Polytechnique Fédérale de Lausanne

Coulson, I. M. & Caldwell, J. A. R. 1985, SAAO Circulars, 9, 5

Feast, M. W., Walker, A.R. 1987, ARA&A, 25, 345

Fernie, J. D. 1990, ApJS, 72, 153

Gieren, W. P. 1981, ApJS, 46, 287

Golay, M. 1980, Vistas in Astronomy, 24, 141

Gorynya, N. A., Samus', N. N., Rastorguev, A. S., & Sachkov, M. E. 1996, Astronomy Letters, 22, 175

Gray, R.O. 1991, A&A, 252, 237

Lloyd Evans, T., 1980, SAAO Circulars, 1, 257

Madore, B. F. 1977, MNRAS, 178, 505

Mermilliod, J.-C., Mayor, M., Burki, G. 1987, A&AS, 70, 389

Metzger, M. R., Caldwell, J. A. R., Schechter, P. L. 1992, AJ, 103, 529

Pont, F., Burki, G. Mayor, M. 1994, A&A, 105, 165

Rufener, F. 1988, Catalogue of stars measured in the Geneva Photometric System (4^{th} ed.), Observatoire de Genève, Switzerland

Stibbs, D. W. N. 1955, MNRAS, 115, 363

Szabados, L. 1989, Communications of the Konkoly Observatory Hungary, 94, 1

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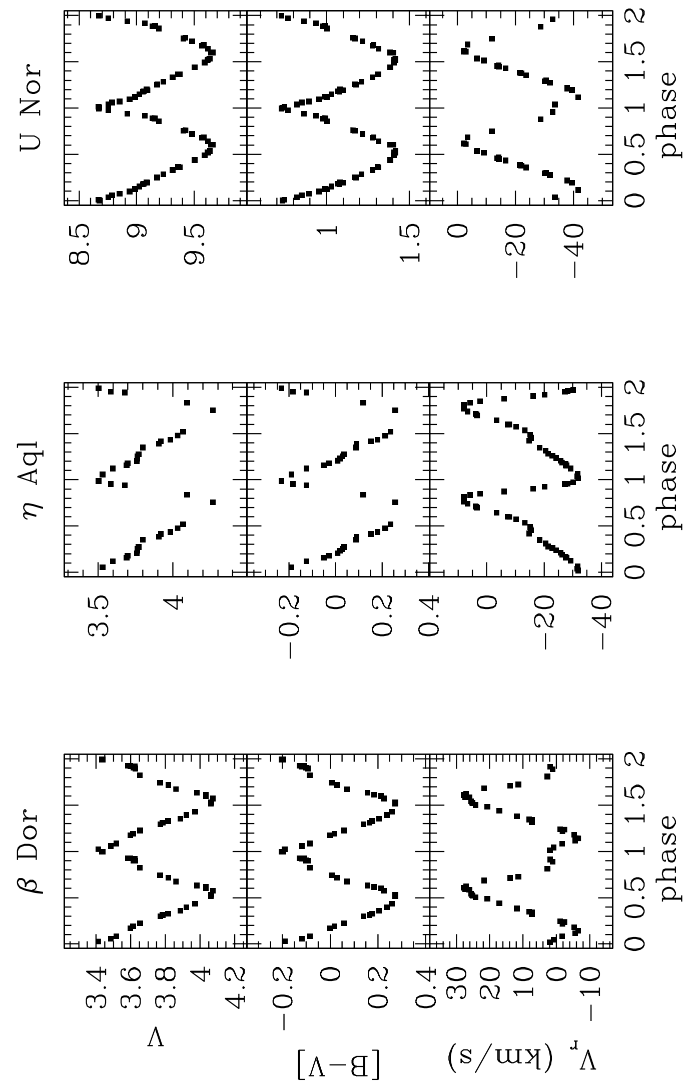

Fig. 1.— The light- (top), color- (middle), and radial velocity (bottom) curves for β Dor (left), η Aql (center) and U Nor (right).

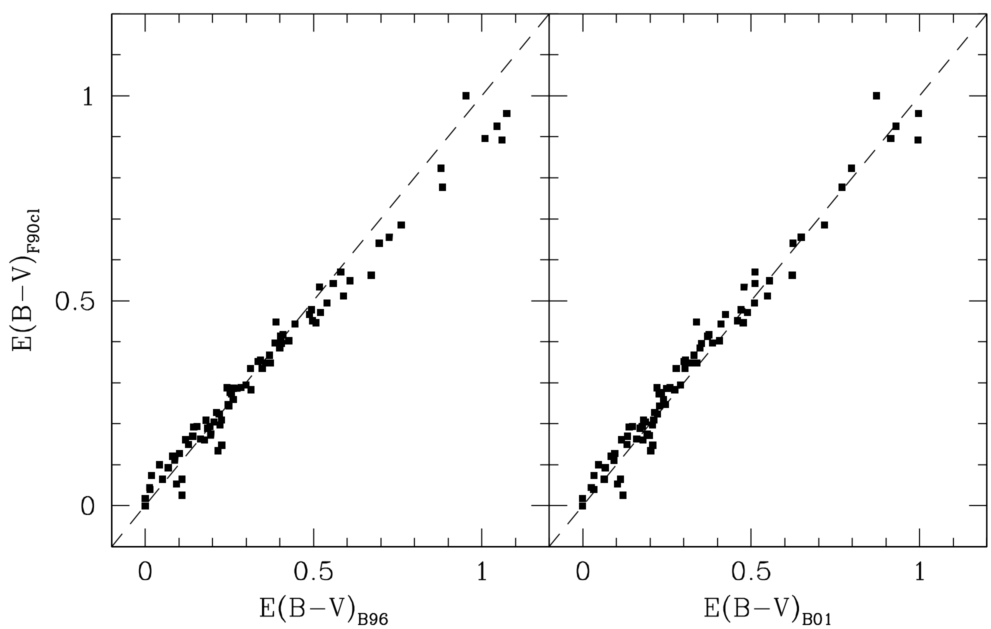

Fig. 2.— Comparison between the reddenings of Fernie (1990) and mine. The left panel shows reddenings determined with the calibration given in Bersier (1996). There is clearly a scale error for $E(B-V) \gtrsim 0.5$. The right panel shows the color excesses computed with the new calibration given in this paper. The line is the one-to-one correspondence.

Table 1. Number of photometric measurements and color excess for each Cepheid

Star	N	$E(B-V)$	Star	N	$E(B-V)$	Star	N	$E(B-V)$	Star	N	$E(B-V)$
SZ Aql	23	0.624	VW Cen	21	0.337	V508 Mon[a]	20	0.328	Y Sgr	15	0.186
TT Aql	28	0.509	XX Cen	25	0.240	R Mus	20	0.083	WZ Sgr	29	0.424
FF Aql	6	0.221	AZ Cen	4	0.179	S Mus	24	0.208	RY Sco	27	0.770
η Aql	19	0.131	KN Cen	24	0.929	UU Mus	21	0.370	KQ Sco	31	0.915
CO Aur[a]	31	0.214	V659 Cen	14	0.202	S Nor[a]	49	0.170	Y Sct	26	0.798
SS CMa	27	0.554	δ Cep	3	0.067	U Nor	41	0.996	Z Sct	21	0.511
U Car	27	0.273	AV Cir	4	0.385	QZ Nor	11	0.233	RU Sct	24	0.998
VY Car	27	0.227	R Cru[a]	111	0.138	V340 Nor[a]	51	0.303	ST Tau[a]	17	0.305
WZ Car	27	0.348	S Cru[a]	113	0.160	Y Oph	3	0.648	SZ Tau[a]	24	0.289
XX Car	24	0.318	T Cru[a]	111	0.147	V440 Per[a]	35	0.226	EU Tau[a]	24	0.198
XY Car	23	0.375	X Cru[a]	111	0.249	X Pup	22	0.410	S TrA	13	0.046
XZ Car	24	0.330	SU Cru	22	0.872	RS Pup	29	0.476	α UMi	5	0.000
YZ Car	37	0.353	BG Cru	24	0.103	VZ Pup	28	0.489	RY Vel	30	0.622
AQ Car	24	0.114	X Cyg[a]	16	0.220	AP Pup	6	0.181	RZ Vel	30	0.278
FR Car	17	0.301	DT Cyg[a]	23	0.033	AQ Pup	29	0.548	SW Vel	26	0.339
GI Car	4	0.191	β Dor	29	0.025	LS Pup	28	0.469	AH Vel	33	0.034
IT Car	4	0.177	DX Gem[a]	21	0.460	MY Pup	29	0.111	DR Vel	28	0.717
l Car	31	0.133	ζ Gem[a]	27	0.000	V335 Pup	6	0.246	T Vul[a]	24	0.064
SU Cas	3	0.258	V473 Lyr[a]	29	0.119	S Sge	5	0.095	SV Vul[a]	16	0.511
DL Cas	4	0.479	T Mon	32	0.211	U Sgr[a]	50	0.406			
V636 Cas[a]	32	0.541	BE Mon[a]	18	0.516	W Sgr[a]	68	0.092			
V Cen	19	0.258	V465 Mon[a]	18	0.283	X Sgr	13	0.207			

[a]Data published in Bersier, Burki, & Burnet (1994). The color excess given here supersedes that given in Bersier (1996).

Table 2. Photometric data for each Cepheid

Star	HJD-2400000	P[a]	V	Q[a]	$U-B$	$V-B$	B_1-B	B_2-B	V_1-B	$G-B$
SZ Aql	49528.825	3	8.946	3	2.554	-1.042	1.425	1.110	-0.211	-0.211
SZ Aql	49529.767	1	8.894	3	2.461	-0.954	1.382	1.126	-0.127	-0.113
SZ Aql	49534.778	3	8.283	3	2.449	-0.708	1.293	1.164	0.099	0.176
SZ Aql	49537.708	3	8.574	3	2.601	-1.026	1.441	1.083	-0.194	-0.178
SZ Aql	49539.720	4	8.807	4	2.772	-1.179	1.511	1.060	-0.341	-0.348
SZ Aql	49541.716	4	9.037	4	2.876	-1.286	1.563	1.037	-0.440	-0.475
SZ Aql	49543.677	3	9.159	3	2.865	-1.293	1.543	1.027	-0.448	-0.482
SZ Aql	49548.682	2	8.060	3	2.367	-0.408	1.154	1.255	0.388	0.511
SZ Aql	49549.694	2	8.040	2	2.374	-0.452	1.187	1.238	0.342	0.454
SZ Aql	49558.650	3	9.018	3	2.859	-1.278	1.564	1.031	-0.434	-0.467

[a] P is the weight of the V magnitude, it goes from 4 (excellent) to 0 (bad data); Q is the weight for the colors; see Rufener (1988) for further details.

Note. — Table 2 is presented in its complete form in the electronic version of the journal. Only a fraction is shown here for guidance regarding its form and content.

Table 3. Number of velocity measurements per Cepheid

Star	N	Star	N	Star	N	Star	N	Star	N	Star	N
U Aql	38	XY Car[a]	6	V659 Cen	3	R Mus	3	AQ Pup	2	RU Sct	33
SZ Aql	31	XZ Car[a]	6	R Cru	35	S Mus	3	LS Pup	1	S TrA	3
TT Aql	43	YZ Car[a]	14	S Cru	40	UU Mus	23	U Sgr[b,c]	32	RY Vel	8
η Aql	28	AQ Car[a]	15	T Cru	39	U Nor	25	X Sgr	2	RZ Vel	18
U Car	16	l Car	19	X Cru	34	SY Nor	29	Y Sgr	17	SW Vel	24
VY Car	16	V Cen	21	SU Cru[a]	31	X Pup	10	WZ Sgr	35	AH Vel[a]	4
WZ Car	6	VW Cen	1	β Dor	30	RS Pup	14	Y Sct	9		
XX Car	6	XX Cen	34	DX Gem[b]	33	VZ Pup	2	Z Sct	8		

[a]More CORAVEL data published by Pont, Burki & Mayor (1994)

[b]More CORAVEL data published by Bersier, Burki, & Burnet (1994)

[c]More CORAVEL data published by Mermilliod, Mayor & Burki (1987)

Table 4. Radial velocity measurements for each Cepheid

Star	HJD-2400000	V_r ($\mathrm{km\,s^{-1}}$)	σ_{V_r} ($\mathrm{km\,s^{-1}}$)
U Aql	48076.734	18.21	0.37
U Aql	48808.691	-12.64	0.38
U Aql	50224.595	-3.44	0.34
U Aql	50226.563	10.20	0.48
U Aql	50227.506	-22.84	0.51
U Aql	50227.598	-22.96	0.46
U Aql	50230.586	-7.57	0.40
U Aql	50274.800	11.62	0.30
U Aql	50275.773	8.94	0.35
U Aql	50276.783	-21.80	0.32

Note. — Table 4 is presented in its complete form in the electronic version of the journal. Only a fraction is shown here for guidance regarding its form and content.